IV. GRAND TETON NATIONAL PARK

A. GENERAL DESCRIPTION

Grand Teton National Park (GRTE) consists of 126,530 ha located in northwestern Wyoming. GRTE is surrounded by Bridger-Teton and Targhee National Forests, and lies 10 km south of Yellowstone National Park (YELL). The park was established to protect the scenic and geological values of the Teton Range and Jackson Hole, and to perpetuate the park's indigenous plant and animal life. Natural resources of the park are managed under ecosystem concepts aimed at perpetuating natural systems rather than individual species or features (GRTE 1995). Approximately 3.7 million people visit GRTE each year.

1. Geology and Soils

The Teton Mountains, a 67-km long range, stretch along a north-south line and reach a height of 4,230 m. The Teton Mountain Range slopes steeply down to Jackson Hole, an intermountain valley about 75 km long and 10 to 20 km wide. The Snake River flows south through the valley, which varies from about 1,800 to 2,100 m elevation. To the east of Jackson Hole are the Absaroka Mountains and to the southeast the Gros Ventre Mountain Range. The lower elevation relief is characterized by several terrace levels and glacial moraines, especially on the west side of the valley. Glacial ice has carved numerous U-shaped valleys and cirques. Erosion has formed deep V-shaped valleys within the mountain range. The park drains into the Snake River, a tributary of the Columbia River.

Late in the Tertiary age, faulting uplifted the mountains on the east side of Jackson Hole. Volcanic activity to the north filled portions of the basin with volcanic conglomerate and tuff. Starley soils developed in these areas. Rhyolite flows from the Yellowstone region covered the northern section and provided the parent material for Hechtman soils. One of the last events of diastrophism was the faulting and uplift of the Teton Mountains and the down-dropping of the Jackson Hole valley floor. This large vertical displacement exposed granite, gneiss and schist, from which Teewinot soils have developed. The sedimentary rocks have all been removed by erosion in the central portion of the range. Sedimentary rocks, and associated Starman and Tongue River soils, persist at the northern and southern ends of the range (Figure IV-1). They are mainly limestone, sandstone, and clay shale. The granite, gneiss, and schist of the high mountain areas of the park are expected to be fairly resistant to weathering and would not be expected to contribute significant amounts of base cations to drainage waters.

Within the past million years, Jackson Hole has experienced numerous periods of glaciation. Most of the ice entered the valley from the high country of the Yellowstone area rather than from the smaller Teton Range. The most recent, the Pinedale glaciation, flowed south through the valley and

Figure IV-1. Soil classifications of GRTE.

Figure IV-1. Soil classifications of GRTE. (Source: GRTE database) created the series of river terraces visible on both sides of the valley (Olson and Bywater 1991). The retreat of the most recent large-scale glaciers occurred about 12,000 to 15,000 years ago. The dozen smaller glaciers now present in the Teton Range are relatively new, having been formed in the last few thousand years. Most surface waters within drainages fed by these glaciers likely receive sufficient contributions of base cations from glacial scouring to render them insensitive to the adverse effects of acidic deposition.

2. Climate

The climate of GRTE is classified as cold-snowy forest with humid winters. Temperature fluctuations are large between summer and winter and between daily maxima and minima due to high elevation and dry air which permits rapid incoming and outgoing radiation. Temperatures can be extremely cold in winter, and below freezing temperatures can be encountered during any month. Meteorological data have been collected in the area of GRTE since 1889 (Dirks and Martner 1982). There is a significant north-south gradient in annual precipitation values in the park region, with highest amounts to the north and lowest amounts to the south in the rain shadow of the high peaks of the Teton Mountains. Winter and spring precipitation tend to be highest (Dirks 1975). Average annual precipitation varies from about 41 cm at Jackson to about 154 cm near the summit of the Teton Mountains. Average annual snowfall varies from about 2 m at Jackson to over 7.7 m at high elevation. Snowmelt generally peaks in May and June. Thunderstorms are frequent during summer. The average annual temperature in Jackson is about 3°C with extremes of -43°C and 38°C. Surface winds display a wide range of prevailing directions and mean speeds depending on the topography and elevation of the site (Dirks and Martner 1982). At the higher locations, the prevailing winds are consistently from the southwest.

3. Biota

Over 1,000 species of vascular plants and over 200 species of fungi occur in GRTE and nearby Teton County, WY. These include 117 exotic species of vascular plants. Ongoing efforts to characterize and classify vegetation at GRTE have culminated in the currently used classification of cover types (Figure IV-2). Loope and Gruell (1973) emphasized the critical influence of fire on vegetation distribution and abundance in the park. Approximately 58% of GRTE is nonforested, consisting of alpine tundra, rock, meadows, grassland, and shrublands. Of the forested portion of the park (Figure IV-3), 28% is lodgepole pine (*Pinus contorta*) forest, 7% Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*), 4% Douglas-fir (*Pseudotsuga menziesii*), 2% whitebark pine (*Pinus albicaulis*), and 1% aspen (*Populus tremuloides*) (Greater Yellowstone Coordinating Committee 1987).

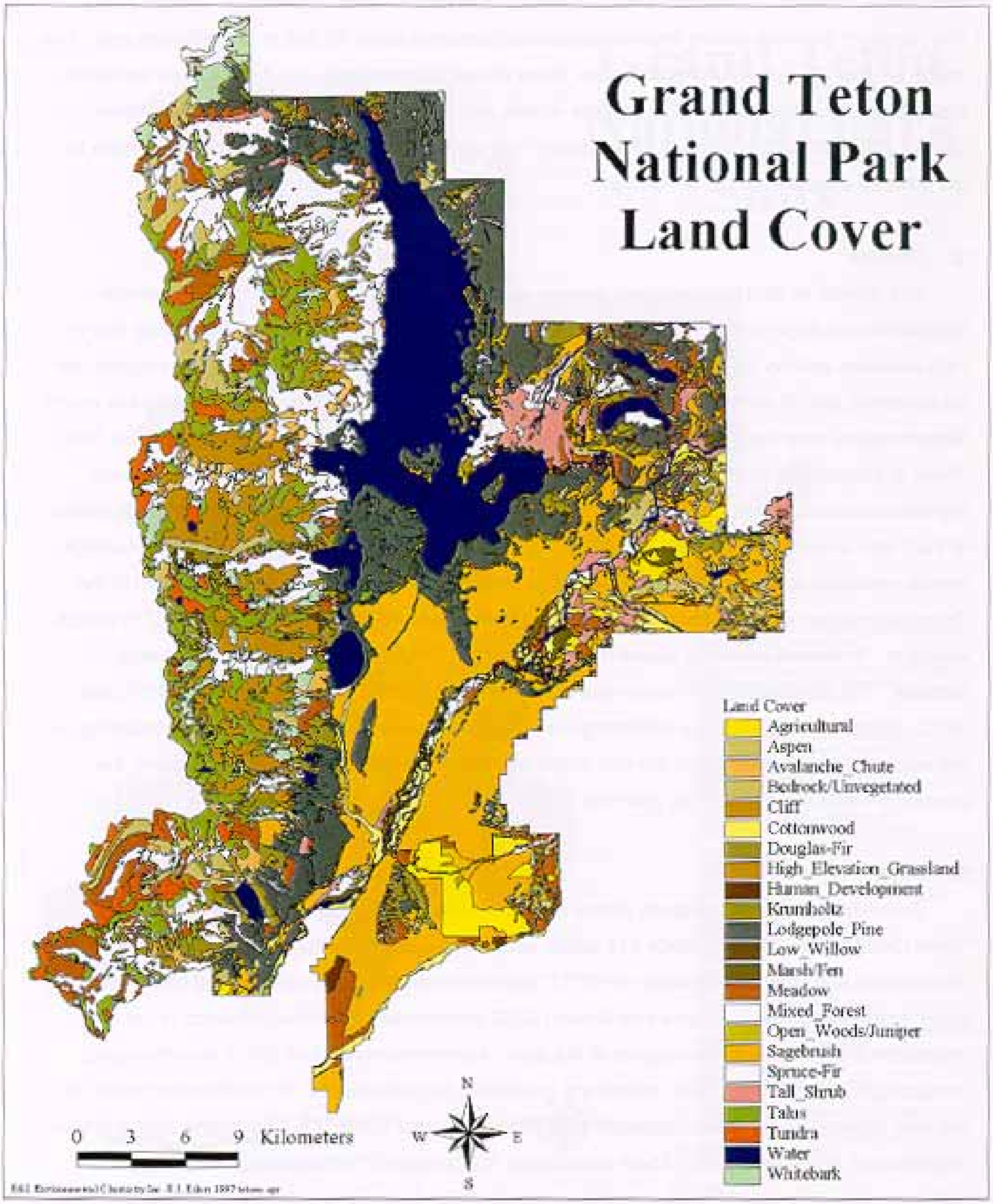

Figure IV-2. Land cover of GRTE.

Figure IV-2. Land cover of GRTE. (Source: GRTE database)

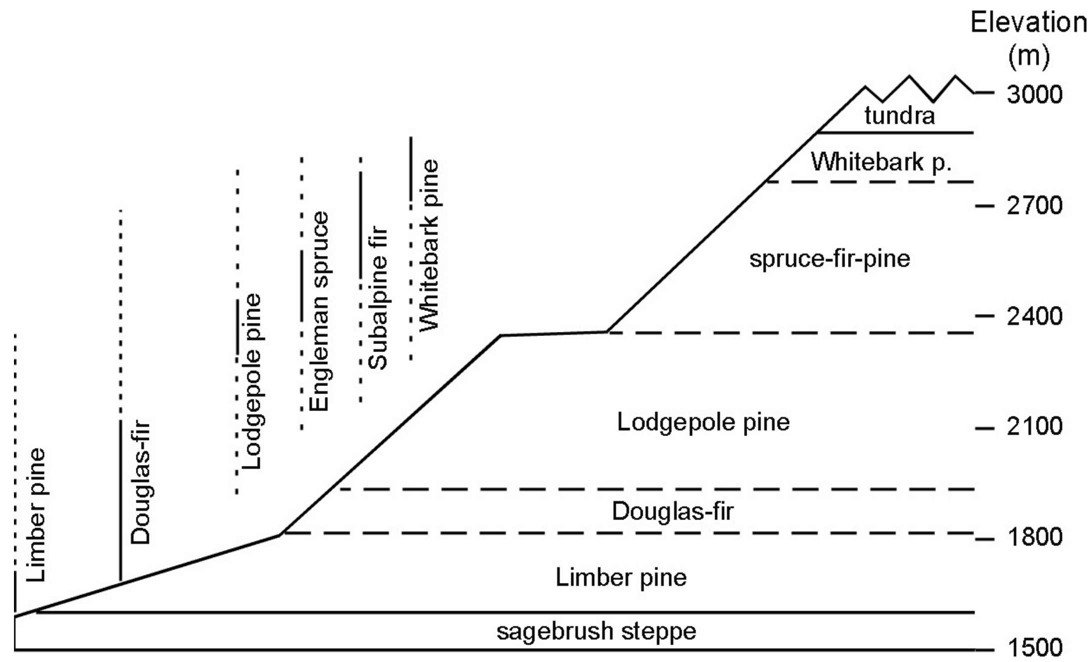

Figure IV-3. The elevational distribution of major forest types near GRTE. The solid vertical lines show the altitudinal ranges over which each tree species is important as a forest dominant; the dotted lines indicate the range over which the species can be found. Adapted from Baker (1976) and Whitlock (1993).

Sagebrush (*Artemisia* spp.) dominates the floor of Jackson Hole, except on glacial moraines where lodgepole pine and spruce-fir are common (Knight 1994), and grows in association with a wide range of other shrub and grass species. Riparian woodlands, which include black cottonwood (*Populus balsamifera* var. *trichocarpa*) and a variety of other hardwoods and conifers, are found adjacent to rivers and streams, often in association with willow (*Salix* sp.) shrublands and other shrub species. Aspen groves are found in areas of higher soil moisture, often in a mosaic with Douglas-fir and sagebrush. Plant communities can be further subdivided into various habitat types according to Steele et al. (1983). Fire and mountain pine beetles (*Dendroctonus ponderosae*) are the primary disturbance agents in the GRTE landscape, and largely help to retain the successional species aspen and lodgepole pine as significant components of the vegetation (Loope and Gruell 1973, Steele et al. 1983). Fire has influenced both the forest and sagebrush communities, although fire frequency is now probably less than it has been in the past due to fire exclusion (Knight 1994). The impact of a beetle epidemic during the 1970s is still visible in places.

There are 54 species of mammals in GRTE, including black bear (*Ursus americana*), elk (*Cervus elaphus*), pronghorn (*Antilocapra americana*), bison (*Bison bison*), moose (*Alces alces*), mule deer (*Odocoileus hemionus*), and several species of smaller mammals. There are over 300 bird species, including white pelican (*Pelecanus erythrorhyncos*), trumpeter swan (*Cygnus buccinator*), sandhill crane (*Grus canadensis*), Canada goose (*Branta canadensis*), bald eagle (*Haliaeetus leucocephalus*), and golden eagle (*Aquila chrysaetos*). There are nine reptile and amphibian species and a cold-water fish fauna of 16 species, including native cutthroat trout (*Oncorhynchus clarki*) and several introduced species of trout.

Gulley and Parker (1985) collected 27 genera of benthos from 46 alpine lakes in the park. Chironomids, limnephilids, and dytiscids were the most widely distributed families found. Other families, including Lestidae and Elmidae, were restricted in their distribution and found only in one basin. The authors tested the hypothesis that the number of benthic genera present in each lake was correlated with the water chemistry and physical conditions of the lakes. Stepwise multiple regression was employed with elevation, log lake surface area, log TMDS (total measured dissolved solids), and pH as independent variables. The only variable that was significantly correlated with the number of benthic genera was elevation ($p < 0.001$), which explained 26% of the variation in number of benthic genera.

Twenty-eight species of zooplankton were identified from the lakes surveyed by Gulley and Parker (1985). Each species and the basins in which it was found is listed in Table IV-1. The zooplankton species found in these lakes were considered to be fairly common high-elevation species. Temperature was the variable most significantly correlated with zooplankton abundance. Zooplankton biomass was positively correlated with temperature and lake surface area. As elevation decreased and lake size and temperature increased, the number of zooplankton species increased. These regressions only explained a small portion (20% to 31%) of the variance in the dependent variables (Gulley and Parker 1985).

Concern has increased in recent years regarding the decline in the populations of amphibians in many areas of the western United States (Wake 1991). Amphibian declines in relatively undisturbed areas such as national parks are of particular concern. Peterson et al. (1992) surveyed amphibians at eight sites in the Greater Yellowstone area during the spring and summer of 1991. Only one site was located in GRTE. Lower Moose Pond is a large inactive beaver pond at 2070 m elevation southwest of Jenny Lake. Western toads (*Bufo boreas)* and spotted frogs (*Rana pretiosa*) had been observed in this area in 1951 (C.C. Carpenter, pers. comm., Peterson et al. 1992). Lower Moose Pond had pH of 6.8 and ANC of 175 μeq/L on the May 25th sampling date. It would be considered insensitive to acidification from acidic deposition. Peterson et al. (1992) found adult, egg, and larval stages of spotted frogs at this site and heard calls (but no sightings) of western chorus frogs (*Pseudacris triseriata*). No other species of amphibians were observed.

Table IV-1. Species of zooplankton collected during the summers of 1982 and 1983 from 70 small lakes in Grand Teton National Park. (Source: Gulley and Parker 1985)

Genus	Species	Drainages[a]
Alona	*guttata*	NS, PB, GR, VA
Bosmina	*longirostris*	GR, AV
Brachionus	*spp*	VA
Camptocercus	*rectirostris*	VA
Ceriodaphnia	*quadrangula*	BP, VA
Ceriodaphnia	*reticulata*	VA
Chaoborus	*spp*	BP, VA
Conochilus	*spp*	VA
Cyclops	*bicuspidatus thomasi*	GR, AV, PB
Cyclops	*spp*	WB, GR, BP, VA
Daphnia	*pulex*	WB, NS, MO, PB, GR, AV, BP, VA
Daphnia	*rosea*	PB, GR, AV
Diaphanosoma	*brachyurum*	VA
Diaptomus	*leptopus*	VA
Diaptomus	*lintoni*	VA
Diaptomus	*shoshone*	WB, NS, MO, GR, AV, VA
Diaptomus	*spp*	WB, NS, MO, LE, PB, GR, AV, SD
Diaptomus	*tyrrelli*	SS, VA
Eucyclops	*agilis*	VA
Eurycercus	*lamellatus*	VA
Holopedium	*gibberum*	NS, SS, PB, VA
Kellicottia	*spp*	NS
Keratella	*spp*	GR, VA
Leptodora	*kindtii*	GR
Macrocyclops	*albidus*	VA
Subclass Ostracoda		VA
Pleuroxus	*procurvatus*	VA
Simocephalus	*vetulus*	VA

[a] AV = Avalanche, LE = Leigh, ND = North Death, SD = South Death, BP = Bearpaw, MP = Moose Ponds, NS = North Snowshoe, SS = South Snowshoe, GG - Glacier Gulch, MO = Moran, PB = Paintbrush, VA = Valley, GR = Garnet, NC = North Cascade, SC = South Cascade, WB = Webb

4. Aquatic Resources

There are about 90 alpine and subalpine lakes and ponds in the park. They are located above about 2700 m elevation. The majority are in remote areas that are difficult to access (Gulley and Parker 1985). Most are less than 10 ha in area. Larger lakes are found at lower elevation. Many lakes in the park were formed behind the terminal moraines of glaciers. Jackson Lake, situated on the Snake River, is the largest natural lake in the area, with a depth of over 120 m and a length of 32 km. Jackson Dam, situated at the natural outlet of Jackson Lake, provides a major storage reservoir on the Snake River. Originally constructed in 1907, it was reconstructed to its current storage capacity of 847,000 acre-feet in 1917. Other large lakes in the park include Leigh Lake, Jenny Lake, and Phelps Lake. All are situated along the border between the valley, Jackson Hole, and the Teton Mountains. The multitude of small lakes and streams are distributed throughout the mountainous areas of the park, especially in the central and southern portions of the range.

The small size, shallow depth, and circular shape, which are typical of the average lake located at high elevation in the Tetons, are indicative of glacially carved lake basins (Hutchinson 1957). The mean maximum depth of alpine lakes in the park is 6.8 m, and the average mean depth is 3.6 m, based on bathymetric measurements of 46 alpine lakes (Gulley and Parker 1985). An important physical-chemical relationship is that between mean lake depth and the amount of dissolved oxygen under the ice in winter. Generally, there is less chance for winter fish kill due to oxygen depletion with increasing mean depth (Wetzel 1975). However, alpine lakes in the Tetons, although mostly shallow, probably do not become anoxic under ice cover because oligotrophic lakes deplete oxygen under the ice very slowly (Mathias and Barcia 1980, Gulley and Parker 1985). Most likely, those lakes shallow enough to winter-kill will freeze solid in winter. This likely occurs in the park in lakes with depths around 1 m (e.g., Nelder and Pennak 1955, Gulley and Parker 1985).

B. EMISSIONS

There is little industrial activity and low population in northwestern Wyoming, resulting in good regional air quality. Most of the industrial activity in Wyoming occurs in the eastern counties near the cities of Gillette and Casper, and in the southwestern counties around Rock Springs. Oil and gas processing, electric utility power plants and industrial fossil-fuel combustion in southwestern Wyoming and southeastern Idaho are the major sources of gaseous pollutants and deposition to the GRTE area. There may also be some long-range transport of pollutants from the Salt Lake City area. Annual emissions of gaseous SO_2, NO_x and VOC in Wyoming are mainly from fossil fuel burning by industrial sources (Tables II-2, II-3 and II-4), and levels are moderate relative to other Western states.

Point sources of SO_2, NO_x, and VOC located within 150 km of GRTE (with emissions exceeding 100 tons/yr) are listed in Table IV-2. Adjacent counties in Idaho and Montana are included. SO_2 emissions in Wyoming are mainly from oil and gas refineries, the largest of which is Amoco

Production Co. (emitting over 1,200 tons/yr) located in Elk Basin, 125 km northeast of GRTE. The largest regional sources of SO_2 within 150 km of GRTE are the Monsanto Company and Nu-West Industries, both mining operations located approximately 100 km south of GRTE in Caribou County, southeastern Idaho. The annual emission of SO_2 from these companies is approximately 9,000 tons/yr combined.

Table IV-2. Point sources of SO_2, NO_x, and VOC in tons per year (annual emissions exceeding 100 tons per year of at least one pollutant) within 150 km of GRTE. (Source: Wyoming Department of Environmental Quality 1995, Martin 1996, Idaho Department of Health and Welfare, unpublished data)

	SO_2	NO_x	VOC
Wyoming			
Amoco Co.	1,218	603	208
Marathon Oil	21	7	869
Oregon Basin Gas	455	25	49
Questar Pipeline		100	10
Williams Field Services (3 sites)		1,381	740
Williston Basin IPC		162	69
Idaho			
Ash Grove Cement	889	802	31
Basic American Foods	498	174	4
Basic American Foods	193	37	54
Chevron Pipeline			437
Idaho National Engineering Labs	91	1,229	35
Idaho Pacific Corp.	131	156	1
Idaho Supreme Potatoes	136	151	1
J.R. Simplot - siding facility	2,554	646	131
Monsanto Co.	4,703	2,021	
Nu-West Industries, Inc.	4,369		
Pillsbury Co.	1	156	7
Montana			
Holnam Inc.	32	1,330	2
Luzenac America	25	242	25
Montana Power Co.		100	25

Sources of NO_x in Wyoming include electric utilities and industrial fossil-fuel combustion (Table II-3). NO_2 was monitored at several sites in the state between 1975 and 1985, and because there were no exceedences of the NAAQS during that time, monitoring was discontinued. Highest levels during the monitoring period were recorded in Rock Springs, approximately 200 km south of GRTE. The largest regional source of NO_x is Monsanto Corporation located in Caribou County, southeastern Idaho. Major stationary sources of VOC emissions, important ozone precursors, are relatively low in Wyoming. However, there are thousands of small VOC and NO_x sources that cumulatively may add up to much higher emission totals (T. Blett, pers. comm.).

Degradation of visibility from particulates is the most important air quality concern in the park. Forest fires and unpaved roads are important sources of particulates. For most visitors, scenic vistas are an important reason for their visit to the park. Seasonal increases in CO and particulates associated with woodburning stoves in Jackson (40 km south of GRTE) and high snowmobile use in the park (Snook 1996) are growing concerns for GRTE.

Potential future impacts on GRTE's natural resources could be caused by the following sources of pollution: (1) increasing residential and business development in Jackson Hole south of the park, including woodburning stoves and fireplaces, automobiles, and air traffic; (2) increasing use of prescribed burning in and around Jackson Hole; (3) proposed oil and gas development and associated activities south, east, and west of the park (including on BLM land); (4) agricultural practices in Idaho west of the park; and (5) metropolitan and industrial development along the western slope of the Wasatch Mountains in the Salt Lake City, Utah area.

C. MONITORING AND RESEARCH ACTIVITIES

1. Air Quality

a. Wet Deposition

There is no deposition monitoring station in GRTE for S and N. However, there is a NADP monitoring station in YELL to the north. Both parks are exposed to the same general air masses, and both experience prevailing winds mostly from the southwest. There are no large point sources of N or S adjacent to either park that might cause major differences in local deposition. We therefore rely on deposition data from YELL to evaluate deposition issues for GRTE.

Precipitation volume and chemistry have been monitored at the NADP site at Tower Junction in YELL since 1980. Annual precipitation amounts are generally in the range of 30 to 45 cm per year at this site. The concentrations of SO_4^{2-}, NO_3^-, and NH_4^+ in precipitation are low, with each generally below 10 μeq/L (Table IV-3). The combined low amount of precipitation and low concentrations of acid-forming precursors in wetfall results in very low levels of S and N deposition. Sulfur deposition is generally well below 1 kg/ha/yr, and N deposition is seldom above this amount (Table IV-4).

Snowpack samples were collected in late March or April from two sites (Rendevous Mountain, Garnet Canyon) in GRTE in 1993 through 1998. Data are currently available for the period through

1997. Sulfate concentrations in snow were similar at the two sites and ranged between 3 and 9 μeq/L (mean, 5 μeq/L at both sites). Nitrate ranges and means were very similar to those for SO_4^{2-} (mean, 5 μeq/L at both sites) and NH_4^+ concentrations were somewhat lower (mean 3 and 4 μeq/L at Rendevous Mountain and Garnet Canyon, respectively). There were no apparent trends from year to year at either of the sites for any of the variables (G.P. Ingersoll, pers. comm.).

Table IV-3. Wetfall chemistry at the NADP/NTN site at Tower Junction, YELL. Note there is no deposition monitoring station in GRTE, although deposition in Yellowstone and GRTE is expected to be very similar. Units are in μeq/L, except precipitation (cm).

Year	Precip	H^+	SO_4^{2-}	NH_4^+	NO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-
1995	38.7	5.3	5.8	7.7	7.7	4.8	0.9	1.8	0.5	1.8
1994	36.3	4.6	9.7	9.8	10.3	12.5	2.3	3.1	0.9	2.5
1993	39.6	2.6	8.6	8.3	8.1	6.6	1.4	2.6	0.4	2.1
1992	45.0	2.7	8.1	8.3	8.5	12.1	2.0	2.0	0.6	2.4
1991	45.5	2.6	11.0	6.8	9.7	14.8	2.7	4.1	0.6	2.5
1990	36.6	3.4	12.0	9.4	11.6	18.4	3.2	3.5	1.2	3.8
1989	42.9	2.1	8.7	8.8	9.4	12.2	2.3	3.0	0.6	3.3
1988	27.3	1.9	7.1	3.5	4.6	9.9	1.7	3.6	0.7	2.6
1987	8.7	2.6	4.5	3.2	4.6	5.7	1.1	2.5	0.3	1.9
1986	38.8	2.8	8.1	5.7	6.7	9.0	1.9	2.5	0.7	2.7
1985	36.1	3.0	6.6	2.9	5.4	6.4	2.0	2.0	0.6	2.5
1984	37.5	5.6	12.2	7.2	9.0	14.4	3.9	4.0	1.4	4.0
1983	34.5	3.6	11.0	5.0	5.8	10.9	2.8	3.8	1.1	3.2
1982	57.1	6.0	12.7	5.0	7.5	11.8	4.1	4.1	1.2	4.0
1981	34.1	4.4	32.6	9.6	11.7	21.9	8.2	26.1	1.6	13.4
1980	24.7	7.4	22.2	11.7	14.6	14.4	3.1	6.8	1.3	5.9
Average	36.5	3.8	11.3	7.1	8.5	11.6	2.7	4.7	0.9	3.7

Table IV-4. Wet deposition (kg/ha/yr) of sulfur and nitrogen at the NADP/NTN site at Tower Junction, YELL. Note there is no deposition monitoring station in GRTE, although deposition in Yellowstone and GRTE is expected to be very similar.

Date	Sulfur	NO_3-N	NH_4-N	Total Inorganic N
1995	0.4	0.4	0.4	0.8
1994	0.6	0.5	0.5	1.0
1993	0.5	0.4	0.5	0.9
1992	0.6	0.5	0.5	1.1
1991	0.8	0.6	0.4	1.1
1990	0.7	0.6	0.5	1.1
1989	0.6	0.6	0.5	1.1
1988	0.3	0.2	0.1	0.3
1987	0.1	0.1	0.0	0.1
1986	0.5	0.4	0.3	0.7
1985	0.4	0.3	0.1	0.4
1984	0.7	0.5	0.4	0.9
1983	0.6	0.3	0.2	0.5
1982	1.2	0.6	0.4	1.0
1981	1.8	0.6	0.5	1.0
1980	0.9	0.5	0.4	0.9
Average	0.7	0.4	0.4	0.8

Table IV-5. Monthly average ozone levels (ppbv) in GRTE for 1995 determined with passive ozone samplers. (Source: Ray 1995, unpublished data)

Month	Monthly ozone average (ppbv)
May	35.6
June	35.8
July	34.9
August	39.1
September	36.6

b. Occult/Dry Deposition

There are no data available on dry or occult deposition of S or N to sensitive resources within GRTE. However, we expect that the contributions of both dry and occult deposition of S and N are low relative to the wet deposition amounts summarized in Table IV-4. This is because there are no significant emission sources in close proximity to the park.

c. Gaseous Monitoring

Gaseous pollutants are not regularly monitored in GRTE, although ozone and SO_2 are monitored in YELL to the north. During the summer of 1995, ozone was monitored in GRTE near park headquarters at Moose Junction using passive ozone samplers. Monthly average ozone levels were between 35 and 39 ppbv (Table IV-5). Passive sampler data were also collected in 1996 and 1997. Because the passive ozone data reflect a mean concentration and do not indicate diurnal variation in ozone levels, it is unknown what the maximum hourly ozone concentrations or the diurnal pattern of exposure were at this site. It is reasonable to assume that concentrations and diurnal patterns are similar to those at YELL, although local sources of NO_x from the Jackson area could facilitate ozone breakdown at night.

2. Water Quality

Alpine lakes in GRTE exhibit a range of characteristics that contribute to their sensitivity to potential acidic deposition impacts (e.g., Marcus et al. 1983): bedrock resistant to weathering, shallow soil, steep slope, low watershed to lake surface area ratio, high lake flushing rate, high precipitation, high snow accumulation, and short growing season.

Surface water alkalinity values tend to be high throughout most of the low elevation areas of the park. Lakes and streams with alkalinity less than 400 μeq/L are generally restricted to the high mountain areas near the western border of the park.

Miller and Bellini (1996) evaluated the trophic status of 17 lakes in GRTE. Phosphorus and chlorophyll *a* concentrations were measured in an effort to detect aspects of lake water quality suggestive of eutrophication. A review of the literature did not yield earlier data on lake trophic status in the park, and the data collected in this study will therefore constitute the baseline for future evaluations of eutrophication in the park. Six of the study lakes were located in the mountains. Samples were collected in July and August and analyzed for specific conductance, pH, and total phosphorus concentrations. Specific conductance was below 20 μS/cm in all of the mountain lakes, suggesting low concentrations of dissolved ions. Two lakes (Amphitheater and Surprise) had very low specific conductance (< 10 μS/cm) and had pH in the range 6.0 to 6.5 (Table IV-6).

Table IV-6. Water quality data collected in 1995 by Miller and Bellini (1996) in mountain lakes of GRTE.

Lake	Approximate Elevation (m)	Lake Area (ha)	Specific Conductance (μS/cm)		pH Measurements	
			July	August	July	August
Amphitheater	3,000	2.4	9.7	8.9	6.0	-
Lake of the Craggs	3,000	4.0	15.3	11.8	8.2	7.7
Delta	2,750	3.2	11.5	9.8	7.9	-
Holly	2,960	3.2	17.4	15.1	8.0	8.1
Solitude	2,800	12.1	7.1	14.8	7.8	8.4
Surprise	2,900	1.2	8.7	8.3	6.5	-

Amphitheater and Surprise Lakes, the smallest of the lakes studied, are located in close proximity to each other, approximately at treeline, on a ridge between Glacier Gulch and Garnet Canyon to the northwest of Bradley Lake. Neither is fed by a glacier. Neither has a significant inlet or outlet stream, based on examination of 7.5-minute maps. The absence of inlet streams, and particularly the absence of glacial meltwater contributions, would be expected to predispose these lakes to acidic deposition effects. Based on the available information, these lakes would be expected to be moderately to highly sensitive to acidification from acidic deposition. Key elements of acid-base chemistry were not measured, however, including alkalinity and the concentrations of base cations, sulfate and nitrate.

Water quality was also measured by Miller and Bellini (1996) for seven moraine lakes, all of which had pH >8.0 and specific conductance greater than about 17 μS/cm. The moraine lakes tend to be larger than the mountain lakes; the smallest was Bradley Lake at 28 ha and the largest, Jenny Lake at 486 ha. These lakes are likely insensitive to acidification from acidic deposition. Similarly, all of the four valley lakes sampled had high specific conductance (> 100 μS/cm) and pH > 8.5 and would not be sensitive to acidic deposition.

Based on the phosphorus and chlorophyll *a* measurements, mountain lakes were oligotrophic to mesotrophic, as were moraine lakes. Trophic status of the valley lakes was more variable, with some in the eutrophic range.

Two lakes within GRTE, and three lakes in proximity to the park, were sampled as part of EPA's Western Lake Survey. None were particularly sensitive to acidic deposition. The lowest measured ANC value was 154 μeq/L, in a lake with pH of 7.3 (Table IV-7). Gulley and Parker (1985) surveyed 70 lakes and ponds in Grand Teton National Park during the months of June, July, and August of 1982 and 1983. Forty-six alpine lakes and ponds and 24 lower-elevation lakes were sampled. The majority of the lakes were relatively dilute, with specific conductance less than about 30 μS/cm. Twenty-two of the lakes were highly dilute, with specific conductance $\leq$10 μS/cm. They were all located at high elevation; all were above 2500 m and most were above 2900 m elevation. All except one (montane) lake were located in alpine settings. Dilute lakes tended to be small; most were less than 2 ha in area. The largest was 6 ha. Watershed areas were also small in most cases (< 100 ha). pH values were generally in the range of 7.0 to 8.0. Only four lakes had pH below 7.0 and two below 6.0. Calcium concentrations were below 30 μeq/L in six of the dilute lakes (Table IV-8).

Lakes and ponds were sampled by Gulley and Parker (1985) in 13 alpine drainage basins within the park (Figure IV-4). An analysis of variance (ANOVA) test was performed to test for differences in major ion chemistry among drainage basins. No significant difference was found among alpine basins for the majority of chemical parameters tested. The only ion to show a significant difference ($p < 0.05$) was for Mg^{2+}, and that difference was driven by the very high Mg^{2+} concentration of one lake (Schoolroom). Gulley and Parker (1985) concluded that the alpine basins of the park exhibited remarkably homogeneous water chemistry. This occurred because of the similar physical, geochemical, and vegetative characteristics of the alpine basins. All basins where lakes were sampled, except Schoolroom Lake and Avalanche Canyon, had bedrock geology of Precambrian gneiss, schist, and granite.

Table IV-7. Results of lakewater chemistry analyses by the Western Lake Survey for selected variables in GRTE and adjacent areas. (Source: Eilers et al. 1987)

Lake name	Lake ID	Lake area (ha)	Watershed area (ha)	Elevation (m)	pH (μeq/L)	ANC (μeq/L)	SO_4^{2-} (μeq/L)	NO_3^- (μeq/L)	Ca^{2+} (μeq/L)	C_B (μeq/L)	DOC mg/L
Lakes Within GRTE											
Grassy L.	4D3-02	117.9	883	2198	7.3	153	18.9	0.3	93	188	1.5
Trapper L.	4D3-07	1.4	367	2107	7.6	435	38.7	2.1	298	491	1.1
Lakes Outside GRTE											
Hidden L.	4D3-02	7.2	129	2214	7.3	241	22.9	0.1	139	285	1.3
Loon L.	4D3-06	9.9	160	1970	7.0	486	21.0	0.3	320	549	4.2
Upper	4D3-06	47.0	3012	2022	8.8	2197	55.7	0.8	1481	2399	1.4

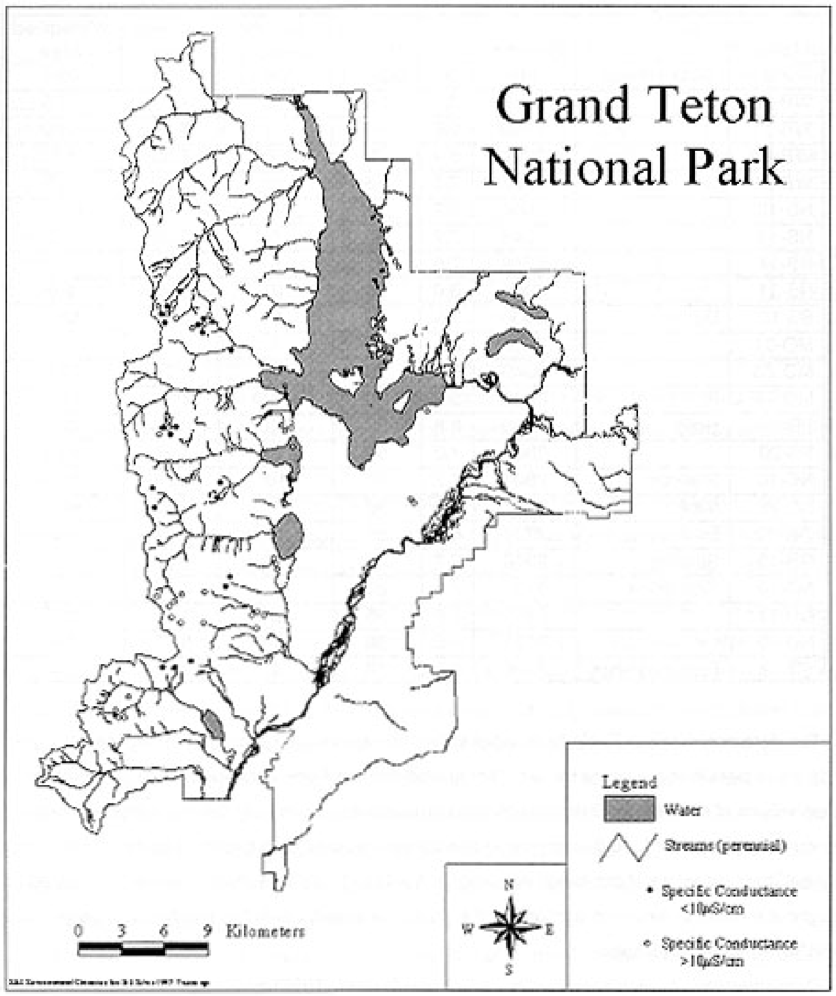

Figure IV-4. Location of lakes sampled by Gulley and Parker in GRTE. Dilute lakes (specific conductance <10 µS/cm) are shaded; other sampled lakes are indicated by open circles. From Gulley and Parker 1985.

Figure IV-4. Location of lakes sampled by Gulley and Parker in GRTE. Dilute lakes (specific conductance <10 μS/cm) are shaded; other sampled lakes are indicated by open circles. From Gulley and Parker 1985.

Table IV-8. Selected characteristics of dilute lakes and ponds (specific conductance ≤10 μS/cm) in GRTE surveyed by Gulley and Parker (1985).							
Lake Number	Lake Name	Elevation (m)	pH	Ca^{2+} (μeq/L)	Specific Conduct. (μS/cm)	Surface Area (ha)	Watershed Area (ha)
WB-02		3048	7.5	50	10	1.31	27.0
WB-11		2966	6.8	80	10	6.26	38.0
WB-20		2757	6.4	70	9	5.89	100.0
WB-21		2957	7.8	55	10	0.32	0.7
NS-10		2804	7.7	240	9	2.26	120.0
NS-13		3048	7.7	50	9	0.28	3.2
NS-14		3048	7.6	30	9	0.33	13.0
NS-21		3048	8.0	65	10	1.39	6.0
SS-10	Dudley	2500	NA	50	9	3.80	89.0
MO-01		2900	8.1	10	3	0.19	2.0
MO-23		3040	5.3	10	7	0.19	13.0
MO-24		3040	5.8	70	8	1.24	27.1
PB-10	Holly	2926	6.6	55	10	2.99	25.0
PB-20		2804	7.0	50	7	1.24	15.0
NC-10	Solitude	2804	7.2	40	10	14.77	180.0
NC-20	Mica	2926	7.5	55	8	3.92	67.0
GG-10	Delta	2791	8.0	80	10	2.69	140.0
GR-13	Surprise	2920	7.7	50	8	0.88	4.2
ND-10	Timberline	3131	7.6	25	6	1.92	27.0
ND-11		3100	8.0	55	9	1.12	86.0
ND-12		3131	8.2	30	8	0.11	5.0
SD-12	Forget-Me-Not	2900	7.1	10	4	0.11	3.0

The data presented in Table IV-8 suggest that there are a large number of alpine lakes and ponds in the park that are sensitive to potential acidification from acidic deposition, as reflected in the low values of specific conductance and calcium concentration. pH values were circumneutral, with two lakes having pH < 6.0, suggesting that chronic acidification probably had not occurred to any significant extent as of the sampling dates in 1982 and 1983. Sensitive lakes are located throughout most high elevation portions of the park, but especially in the northcentral portion of the Grand Teton Mountain Range.

Only a few alpine lakes sampled by Gulley and Parker (1985) had specific conductance >30 μS/cm (Table IV-9). For example, Schoolroom Lake, located at the base of Schoolroom Glacier, had a conductivity of 57 μS/cm, three times higher than other alpine lakes in the park, and total hardness equal to 31 mg/L as $CaCO_3$. Glacial silt from sedimentary rocks in the catchment at Schoolroom Lake affects the water chemistry of the lake by making its concentration of base cations higher than other alpine lakes in the region. In contrast, Delta Lake is situated directly below Teton

Table IV-9. Descriptive statistics for chemical data from 46 alpine lakes in GRTE (surface waters only). The symbol * means below detection limit. (Source: Gulley and Parker 1985)					
Chemical Variable	Minimum	Maximum	Mean	Standard Deviation	Median
pH	5.3	8.6	7.3	0.1	7.4
Conductivity (μS/cm)	3.0	57.0	15.6	1.8	11.8
Total Hardness (as mg/L $CaCO_3$)	0.4	59.7	6.8	1.5	4.0
Ca^{2+} (μeq/L)	*	199.6	104.8	20.0	64.9
Mg^{2+} (μeq/L)	*	156.4	24.7	4.9	16.5
Alkalinity (μeq/L, converted from mg/L $CaCO_3$)	8	760	110	20	74
Cl^- (μeq/L)	28.2	375.1	132.5	11.3	124.1
Total Dissolved Solids (mg/L)	2.7	70.8	13.8	1.8	10.8

Glacier, but is much more dilute (total hardness equal to 4.0 mg/L as $CaCO_3$). Like Schoolroom Lake, Delta Lake receives large contributions of glacial silt. Teton Glacier resides on granite, gneiss, and schist, whereas Schoolroom Glacier is on limestone and dolomite (Gulley and Parker 1985).

Williams and Tonnessen (in review) sampled seventeen high-elevation headwater lakes throughout and adjacent to GRTE in August, 1996. Although none were acidic, about half had ANC values near 50 μeq/L, and almost all had ANC below 200 μeq/L. About one-third had pH in the range of 5.8 to 6.0. These data do not suggest that chronic lakewater acidification has occurred but do suggest sensitivity, especially to episodic acidification. Of particular importance was the observed concentrations of NO_3^-, which were relatively high in many of the lakes sampled. Six had NO_3^- concentrations in the range of 5 to 10 μeq/L and three had NO_3^- concentrations greater than 10 μeq/L (to a maximum of 13 μeq/L). Given that the lakes were sampled at the end of the growing season, these data suggest that the capacity for biological uptake of N has been reached due to current levels of N inputs. It is likely that future increase in N deposition to these watersheds would contribute to higher lakewater NO_3^- concentrations and possible chronic acidification. Furthermore, the observed high NO_3^- concentrations suggest that additional water quality data should be collected during early summer, during the snowmelt period.

Of the lakes sampled more recently in GRTE by Williams and Tonnessen (in review), those having the lowest ANC were Surprise and Amphitheater (ANC=50 and 63 μeq/L, respectively). These were also the two lakes having the lowest specific conductance (5 and 6 μS/cm, respectively). Both had very low concentration of SO_4^{2-} (6 μeq/L) and no measurable NO_3^-. There were also, however, some relatively low-ANC (< 100 μeq/L) lakes that had $NO_3^- > 5$ μeq/L (Delta, Holly, and LOTC). Any of these five lakes might be good candidates for inclusion in future monitoring efforts.

3. Terrestrial

Management priorities for terrestrial resources in GRTE include wildlife and habitat protection, control of the 117 exotic plant species, and management of approximately 3.7 million visitors each year. Development and the impact of visitors on habitat quality are major concerns of resource managers. Project statements in the Resource Management Plan address elk, moose, bighorn sheep, raptors, small mammal, bird and fish populations. At present there are no research or monitoring projects underway focusing on air pollution impacts on vegetation and other terrestrial resources in GRTE.

D. AIR QUALITY RELATED VALUES

1. Aquatic Biota

Sensitive fish species in the park include both native and non-native salmonids. Recent studies have shown that native western trout are sensitive to short-term increases in acidity. For example, Woodward et al. (1989) exposed native western cutthroat trout to pH depressions (pH 4.5 to 6.5) in the laboratory. Freshly-fertilized egg, eyed embryo, alevin, and swim-up larval stages of development were exposed to low pH for a period of seven days. Fish life stages were monitored for mortality, growth, and development to 40 days posthatch. The test fish were taken from the Snake River in Wyoming. Reductions in pH from 6.5 to 6.0 in low-calcium water (70 μeq/L) did not affect survival, but did reduce growth of swim-up larvae. Eggs, alevins, and swim-up larvae showed significantly higher mortality at pH 4.5 as compared to pH 6.5. Mortality was also somewhat higher at pH 5.0, but only statistically higher for eggs.

It is unlikely that aquatic biota in GRTE have experienced adverse impacts to date from acidic deposition. This is because deposition of S and N are apparently low, and the available lake water chemistry data are not indicative of chronic acidification. However, in view of the high sensitivity of lakewater chemistry to adverse effects of possible future increases in acidic deposition, aquatic biota constitute important AQRVs within the park.

2. Terrestrial Biota

Vegetation is the resource which is most sensitive to ozone and SO_2, and a few tree species found in GRTE have been identified as potential bioindicators (see below). Ozone and SO_2 levels have probably not exceeded the NAAQS in GRTE. Baseline data on the condition of sensitive species would be helpful for future comparisons if pollutant levels increase. Monitoring sensitive receptors (those species with known sensitivity to one or more pollutants) by using detailed descriptions and classifications of leaf or plant injury would be useful for long-term evaluation of ecosystem health.

One of the most ozone-sensitive western tree species is ponderosa pine (*Pinus ponderosa*, especially var. *ponderosa*), for which extensive data are available on field (Miller and Millecan 1971, Pronos and Vogler 1981, Peterson and Arbaugh 1988) and experimental (Temple et al. 1992) exposures. The evidence for ozone impacts on ponderosa pine is based on observable symptoms and reduced growth (Peterson et al. 1991, Peterson and Arbaugh 1992) as well as physiological (Darrall 1989, Bytnerowicz and Grulke 1992) data. The cause-and-effect relationship, especially for trees growing in forests of southern California and the southern Sierra Nevada, is clear and quantifiable.

The well-documented symptomatology of pines makes lodgepole pine an appropriate bioindicator for ozone, even if it is less sensitive than ponderosa pine (which is not found at GRTE). Lodgepole pine is widespread in GRTE, and several areas in the park are suitable for establishing long-term monitoring plots.

Of the hardwood species present at GRTE, quaking aspen is the most sensitive to ozone. Aspen grows at various locations in riparian ecosystems and in fire- or avalanche-disturbed areas in the park. Numerous studies have documented the sensitivity of this species to ozone under field and experimental conditions (Wang et al. 1986, Karnosky et al. 1992, Coleman et al. 1996) although there is considerable variability in sensitivity among different genotypes (Berrang et al. 1986). Diagnostic ozone symptomatology for aspen includes chlorosis, stippling, necrotic spotting, and leaf margin burn. Symptoms generally vary seasonally, with stippling being most prominent in the spring and black, bifacial (both leaf surfaces) necrosis appearing in late summer (J.P. Bennett, pers. comm.). Great care must be taken in distinguishing ozone symptoms from the effects of various pathogens and insect herbivores commonly found on this species.

Aspen is also considered to be sensitive to SO_2 and may be the best sensitive receptor for this gaseous pollutant. Injury is similar to that normally found for ozone (stippling, followed by bifacial necrosis), although SO_2 -induced injury rapidly bleaches to a light tan color (ozone injury remains dark) (Karnosky 1976). Diagnosis of SO_2 injury must be carefully differentiated from ozone injury.

Black cottonwood is another potential sensitive receptor for ozone (Woo 1996) which has symptoms similar to those of aspen. However, it is generally regarded as less sensitive to ozone than aspen. Neither of these hardwood species has the clarity of ozone symptomatology found in ponderosa pine.

A species list of native plants is available in the NPFlora database. Table IV-10 summarizes vascular plant species of GRTE with known sensitivity to ozone, SO_2 and NO_x. This table is based on a variety of sources from the published literature and other information. It should be noted that the various sources used a wide range of field and experimental approaches to determine pollutant pathology, and that sensitivity ratings are general estimates based on published information and our expert opinion. While it will not be possible for Park staff to collect data on all the species indicated

Table IV-10. Plant species of GRTE with known sensitivities to SO_2, ozone, and NO_x. (H=high, M=medium, L=low, blank=unknown). (Sources: Esserlieu and Olson 1986, Bunin 1990, Peterson et al. 1993, National Park Service 1994, Electric Power Research Institute 1995, Binkley et al. 1996, Brace 1996)

Species Name	SO_2 Sensitivity	O_3 Sensitivity	NO_x Sensitivity
Abies lasiocarpa	L	L	
Acer glabrum	H		
Achillea millefolium		L	
Agastache urticifolia		M	
Agoseris glauca	M		
Amelanchier alnifolia	H	M	
Angelica pinnata		L	
Arctostaphylos UVa-ursi	L	L	
Artemisia tridentata	L	L	
Betula occidentalis	M		
Bromus carinatus		L	
Bromus tectorum		M	
Calochortus nuttllii		L	
Ceanothus velutinus	L		
Cerocarpus ledifolius	M		
Cichorium intybus		L	
Cirsium arvense		L	
Clematis ligusticifolia	M		
Collomia linearis		L	
Conium maculatum		L	
Convolvulus arvensis	H		
Cornus stolonifera	M	L	
Crataegus douglasii	L		
Descurainia californica		L	
Descurainia pinnata		L	
Epilobium angustifolium		L	
Erigeron peregrinus		L	
Erodium cicutarium	L	M	
Festuca idahoensis	H		
Fragaria virginiana		H	
Galium bifolium		L	
Geranium richardsonii	M	M	
Hackelia floribunda	L		
Hedysarum boreale		M	
Helianthus anuus	H	L	
Juniperus communis	L		
Juniperus scopulorum	L		
Lemna minor	L		
Lonicera involucrata	L	H	
Medicago sativa		M	

Mimulus guttatus		L	
Oryzopsis hymenoides	M		

Table IV-10. Continued.

Species Name	SO_2 Sensitivity	O_3 Sensitivity	NO_x Sensitivity
Osmorhiza occidentalis		L	
Phacelia heterophylla		L	
Phyllodoce empetriformis		L	
Picea engelmannii	M	L	
Picea pungens	M	L	
Pinus contorta	M	M	H
Pinus flexilis	L		
Poa annua	H	L	
Poa pratensis		L	
Polygonum douglasii		L	
Populus angustifolia	M		
Populus balsamifera	M	H	
Populus balsamifera subsp. *trichocarpa*	M	H	
Populus tremuloides	H	H	
Potentilla flabellifolia		L	
Potentilla fruticosa		L	
Prunus virginiana	M	H	
Pseudotsuga menziesii	M	L	H
Rhus trilobata	L	H	
Ribes viscosissimum	M		
Rosa woodsii	M	L	
Rubus idaeus	H		
Rubus parviflorus		M	
Rumex crispus		L	
Salix scouleriana		M	
Sambucus melanocarpa		M	
Sambucus racemosa		L	
Senecio serra		H	
Shepherdia canadensis	L		
Sorbus scopulina	M		
Symphoricarpos oreophilus	M		
Taraxacum officinale		L	
Thalictrum fendleri		L	
Toxicodendron radicans	L	L	
Tragopogon dubius	M		
Trifolium pratense	L		
Trifolium repens		H	
Trisetum spicatum	M		
Urtica gracilis		L	
Vaccinium membranaceum		M	

Veronica anagallis-aquatica		L	
Vicia americana		L	
Viola adunca		L	

in Table IV-10, the list can be used by Park managers as a guide for species that could have visible symptoms. Of the many plant species in GRTE, it is likely that there are many other species which have high sensitivity to air pollution, but we currently have no information about them.

An inventory of lichen species with known sensitivity to ozone and SO_2 is summarized in Table IV-11. As in Table IV-10, this table is based on a variety of sources from the published literature and other information. It should be noted that diagnostic symptoms of air pollutant injury to lichens are difficult to identify, and that some species show reduced productivity or even mortality without exhibiting visible symptoms (Nash and Wirth 1988). One of the best sources of background information and guidelines for addressing the use of lichens as sensitive receptors of air pollution is Stolte et al. (1993). Inventories of lichen species distribution and abundance in GRTE would provide a better baseline for further assessment of potential impacts of air pollution on lichens in the park.

Table IV-11. Lichen species of GRTE with known sensitivity to SO_2 and ozone. (H=high, M=medium, L=low, blank=unknown). (Sources: Peterson et al. 1993, National Park Service 1994, Electric Power Research Institute 1995, Binkley et al. 1996)

Species Name	SO_2 sensitivity	Ozone sensitivity
Bryoria fuscescens	M	
Buellia punctata	L-M	
Caloplaca cerina	M-H	
Caloplaca flavorubescens	H	
Caloplaca holocarpa	M	
Candelaria concolor	M-H	
Candelariella vitellina	M	
Candelariella xanthostigma	M	
Cetraria pinastri	M	
Cladonia chlorophaea	M	
Cladonia coniocraea	M	
Cladonia fimbriata	M-H	
Cladonia gracilis	L-M	
Collema tenax	M	
Evernia mesomorpha	M	
Hyperphyscia adglutinata	M	
Hypogymnia physodes	M	
Hypogymnia tubulosa	H	
Lecanora chlarotera	M	

Lecanora dispersa	L	
Lecanora hageni	L-M	
Lecanora muralis	M	
Lecanora saligna	M	
Lecidea atrobrunnea	L	
Parmelia caperata	M	
Parmelia subargentifera	M	
Table IV-11. Continued		
Species Name	SO_2 sensitivity	Ozone sensitivity
Parmelia subaurifera	H	
Parmelia subolivacea		L
Parmelia sulcata	L-H	M-H
Peltigera canina	L	H
Physcia adscendens	M	
Physcia aipolia	M	
Physcia caesia	M	
Physcia dubia	M	
Physcia millegrana	M	
Physcia stellaris	M	
Physconia detersa	M-H	L
Rhizoplaca chrysoleuca	H	
Rhizoplaca melanophthalma	H	
Usnea hirta	M	
Usnea subfloridana	M-H	
Xanthoria elegans	M	
Xanthoria fallax	M-H	
Xanthoria polycarpa	M-H	L

E. RESEARCH AND MONITORING NEEDS

1. Deposition and Gaseous Pollutants

GRTE and YELL are within the same airshed, and although data from YELL monitoring sites can be used to infer GRTE air quality, there also may be local sources of CO, SO_2, NO_x, VOC, and particulates which influence air quality within GRTE. Also, transported pollutants from southeastern Idaho and Utah may be deposited at higher concentrations in GRTE than YELL due to topography and airflow-circulation patterns. Monitoring of SO_2, NO_x, and ozone at GRTE would provide a more accurate picture of air quality in the park. Even a short period of monitoring would be helpful because the data could be calibrated with YELL data, giving YELL data predictive power for GRTE in the future. Given the observed greater sensitivity of aquatic resources in GRTE, as compared to YELL, to potential future increases in sulfur or nitrogen deposition, it would be desirable to monitor deposition within GRTE. Although we do not view this as a critical need at this time, installation of a wet deposition monitoring station in GRTE would be useful. If this is done, we recommend installation at the highest elevation that is practical in the mid-section of the park (in the vicinity of Jenny Lake).

Little is known of the present threats of ozone, SO_2 and NO_2 on native vegetation in GRTE. Ozone data are currently collected at YELL using a continuous analyzer. A second continuous analyzer installed seasonally (during the summer months) at a high elevation site in YELL or preferably in GRTE for three consecutive years would provide valuable information on the diurnal pattern of ozone exposure within the park. Studies of ozone profiles done in other mountainous areas including the Swiss Alps (Sandroni et al. 1994), Sierra Nevada (Miller et al. 1989) and Cascade Mountains (Brace 1996, 1998) have shown that topography and elevation can influence the diurnal exposure. Low-elevation sites have diurnal profiles characterized by low ozone levels during the nighttime and early morning hours, maximum levels during the mid or late afternoon, and low levels again in the evening. High elevation sites typically have lower maximum ozone concentrations than low elevation sites, but ozone remains elevated during the morning and nighttime hours. Plant species at higher elevations may be at particular risk from exposure to elevated levels of ambient ozone during the morning hours when they are physiologically active.

It would be useful to determine the spatial variability in ozone concentration across an elevational gradient. A network of passive ozone samplers could be established to compare ozone measurements from different locations in GRTE. During the summer months, a network of passive ozone samplers installed for three consecutive years would provide the data to describe spatial patterns and a reference point in time. The network should include one transect of four sites placed along an elevational gradient, ranging from Moose to above treeline. An additional transect of three sites along a north-south transect would provide data on the spatial variability of weekly ozone exposures in different areas of the park.

SO_2 monitoring is important considering the proximity of regional point sources of SO_2. An SO_2 analyzer in operation for two years every five years would provide important data on long-term impacts of regional SO_2 emissions on air quality in GRTE. SO_2 emissions from industrial sources upwind of GRTE may be expected to grow as demands on power generation, mining operations and oil and gas production increase. By installing an analyzer now, it will be possible to assess both current air quality and future impacts.

2. Aquatic Systems

Gulley and Parker (1985) recommended continued monitoring of eight alpine lakes in the park, selected on the basis of human use (high and low) and lake type defined on the basis of cluster analysis. The lakes recommended for monitoring ranged from those that we expect to be highly sensitive to potential acidification (Surprise Lake, Solitude Lake, Kit Lake), to those we expect to be moderately sensitive (Holly Lake, Grizzly Bear Lake), to one expected to be insensitive (Snowdrift Lake), based on calcium concentrations, specific conductance, and alkalinity. We suggest a monitoring strategy that focuses only on the highly-sensitive systems.

We believe that there is insufficient information on aquatic resources relative to air pollution effects for GRTE, particularly in the high mountain areas which are sensitive to acidification effects. Based on the limited data available, it appears that at least some and perhaps many of the high-elevation lakes in the park have very low specific conductance (< 10 μS/cm) and low ANC and are presumably sensitive to acidic deposition effects. We recommend a modest monitoring project to ascertain the major ion chemistry and biology of some high-elevation lakes in the park that are presumed sensitive to acidification. Based on the results of that monitoring effort, we recommend formulation of a viable long-term monitoring strategy for a small group (perhaps two or three) of the high-elevation lakes.

There is also a need for additional episodic monitoring of surface water chemistry in sensitive surface waters in GRTE. Such monitoring would entail collection of lakewater and streamwater chemistry soon after ice out on high-elevation lakes. In many cases, safety considerations prevent sampling during the early phases of snowmelt, but collection of monitoring data in late June or early July would be very useful. These data would help to 1) clarify the extent to which episodic acidification occurs under current deposition, 2) quantify the relative roles of S and N in episodic acidification of aquatic resources in the park, and 3) establish a baseline for episodic acidification for comparison with future years when deposition may be higher. We recommend a sampling program of about 10 lakes and streams, distributed across the known (and presumed) sensitive portions of the park, to be sampled three times per year at approximately monthly intervals for three years from the earliest practical sampling date for each watershed.

Based on the observed high degree of sensitivity of several lakes in GRTE to future increase in acidic deposition, we recommend modeling of one or more watersheds to better quantify the loading rates for S and N above which adverse impacts would be expected, based on current scientific understanding. Such a modeling effort is currently underway (contact: K. Tonnessen, ARD, Denver).

3. Terrestrial Systems

Vegetative monitoring for pollutant effects is not recommended for GRTE at this time. Past and current gaseous pollutant monitoring efforts have not revealed a serious threat to terrestrial resources. If SO_2 or NO_X emissions outside the park increase substantially in the future, vegetation monitoring should be initiated. In this event, three levels of monitoring, with increasing amounts of effort and expense, are presented in Appendix A. These monitoring activities are based on methods and protocols developed by the USDA Forest Service and National Park Service. Species and locations recommended for monitoring are listed below.

Lodgepole pine and quaking aspen plots could be established in the general vicinity of Moose. These plots should be located away from human-use areas and preferably in areas with good air flow. Lichen surveys (perhaps every five years) could be conducted to determine the total lichen flora at GRTE. Lichen monitoring methodology is described in Appendix A. A large-scale monitoring effort for lichens is not justified at this point, although protocols and guidelines in Stolte et al. (1993)

can be consulted for information on assessing injury.

If necessary, additional tree plots should be located: (1) near Moran, and (2) approximately half way between Moose and Moran. These areas and the Moose area are all located along the Snake River drainage where maximum air flow can be expected. Locations of these plots can be changed to other sites in GRTE if ambient air quality data indicate that other areas have a higher risk of pollutant effects. Additional plots that evaluate other conifer species, such as Engelmann spruce, Douglas-fir, and whitebark pine could also be established. If monitoring of herbaceous plants is desirable in the future, candidate species in GRTE include strawberry (*Fragaria virginiana),* skunkbush (*Rhus trilobata*), and red clover (*Trifolium repens*). Herbaceous species monitoring methodology is described in Appendix A.

4. Visibility

Visibility monitoring is not currently conducted at GRTE. Therefore, establishment of monitoring (particle and optical) would help assess visibility conditions at the park. Due to elevational differences between the YELL visibility monitoring site and GRTE, the extent to which the monitoring data collected at YELL represent conditions at GRTE remains uncertain.